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TECHNICAL REPORT 8602

TERTIARY TREATMENT OF EFFLUENT FROM HOLSTON AAP
INDUSTRIAL LIQUID WASTE TREATMENT FACILITY
V. DEGRADATION OF NITRAMINES IN HOLSTON AAP WASTEWATERS
BY ULTRAVIOLET RADIATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) ✓ Samples of Holston Army Ammunition Plant wastewater taken from the B-line, the neutralization basin, the anoxic filter effluent, and the treatment plant final effluent have been treated for removal of nitramines (RDX, HMX, TAX, and SEX) by ultraviolet radiation. An energy requirement of 1.76 watt-hr per gallon of plant effluent is estimated for destruction of all nitramines to their detection limits, corresponding to a uniform annual cost of approximately \$0.41 per 1,000 gallons. This compares very favorably to		

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20. Abstract (continued)

costs estimated for treatment with granular activated carbon. In separate product studies with individual nitramines, 80 to 90 percent of all oxidized nitrogen could be accounted for as inorganic nitrite and nitrate.



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PREFACE

This research was performed under R&D Project No. 1L162720D048, US Army Toxic and Hazardous Materials Agency. Project Officer was Janet Mahannah. This study was part of the AMCCOM Pollution Abatement and Environmental Control Technology Program. Ion chromatographic analyses were performed by Louanna Baxter.

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INTRODUCTION

Composition B, an intimate mixture of 60.7 percent 1,3,5-trinitro-1,3,5-triazine (RDX), 38.7 percent 2,4,6-trinitrotoluene (TNT) and 0.8 percent wax binder, is the most extensively produced composite explosive in the inventory of the US Army.¹ RDX is currently manufactured at Holston Army Ammunition Plant (HSAAP), where it is combined with TNT procured elsewhere. The chemical process involves nitration of hexamethylenetetramine in the presence of acetic anhydride; wastewaters undergo neutralization, denitrification, biological oxidation, and dual media filtration. Holston Army Ammunition Plant is projected to produce 12.3 million gallons of process wastewaters per day at full mobilization. The current design of the Industrial Liquid Waste Treatment Plant (ILWTP) does not provide a tertiary mode of treatment for removal of pollutant chemicals that survive secondary treatment. There is evidence that RDX, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocene (HMX, an explosive and propellant co-produced with RDX), and TNT, as well as by-product nitramines, such as hexahydro-1(N)-acetyl-3,5-dinitro-1,3,5-triazine (TAX) and octahydro-1(N)-acetyl-3,5,7-trinitro-1,3,5,7-tetrazocene (SEX), will survive biological treatment, at least in part, and may adversely affect receiving waters. A problem is foreseen in complying with proposed drinking water criteria of 0.049 mg/L for TNT and 0.035 mg/L for RDX/HMX and ambient criteria of 0.06 mg/L for TNT and 0.3 mg/L for RDX/HMX for protection of aquatic life, based on studies by US Army Medical Bioengineering Research and Development Laboratory (USAMBRDL).²

In previous studies, USAMBRDL has shown that reduction in levels of these nitrobodyes in water can be achieved by carbon adsorption,³ ultraviolet (UV) radiation,^{4,5} UV-ozone,⁴ UV and hydrogen peroxide,⁵ or corona oxidation (subsequently rejected because of high energy requirements).⁶ Of all the HSAAP wastewater nitrobodyes, TNT is most readily removed by carbon adsorption and least readily removed by UV radiation, added oxidant being necessary to achieve degradation rates comparable with those of the nitramines (RDX, HMX, TAX, and SEX).

Beginning in 1984, USAMBRDL has monitored nitrobody levels at various locations at the ILWTP; results are presented in Table 1. In no instance has TNT been found above the detection limit of 0.05 mg/L. Since the rates of photodegradation of nitramines are not significantly enhanced by oxidizing agents,^{4,5} the absence of TNT in HSAAP wastewaters makes treatment by UV radiation alone a potentially attractive tertiary process. Smith⁷ has recently completed a definitive study of the treatment of HSAAP wastewaters with activated carbon and costs associated therewith, which affords an excellent opportunity for comparison of the two methods for reduction of nitramine levels.

TABLE 1. NITRAMINE CONCENTRATIONS AT THE ILWTP^a

Station (No. of samples)	Nitramines, mg/L (standard deviation)			
	RDX	IMX	TAX	SEX
B-Line Wastewater (32)	6.095(1.819)	2.201(0.339)	3.430(1.610)	1.708(0.706)
Neutralization Basin (48)	4.736(1.552)	1.756(0.341)	2.504(1.130)	1.353(0.537)
Anoxic Filter Effl. (31)	1.213(0.825)	1.010(0.508)	1.532(0.890)	1.359(1.166)
Final Plant Effl. (36)	2.600(0.482)	1.536(0.269)	< 0.07	1.347(1.195)

a. Samples collected from August through December 1985.

EXPERIMENTAL PROCEDURES

EQUIPMENT

The stainless steel reactor, described previously, is 6.6 in (16.8 cm) in diameter and 78 in (2 m) tall, with a useful liquid volume of 38 L.⁴ An 80-watt UV lamp (estimated 34-watt output) incased in a 1 in (2.5 cm) quartz tube and running vertically through the center of the column emits maximum radiation at a wavelength of 253.7 nm. In the radiation-only mode, reactor contents are mixed by recirculation at ca. 6 L/min.

PROCEDURE

Wastewater samples (18 L) from various stations at the ILWTP were transferred by air to USAMBRDL the day of collection and refrigerated until use (no more than 48 hours). The samples were pumped into the reactor and irradiated at ambient temperature, 100 mL aliquots being removed at regular intervals. Munitions analyses were carried out by high performance liquid chromatography (HPLC) using a UV detector, as described by Brueggemann; detection limits varied from 0.05 to 0.07 mg/L, depending on the nature of the sample.⁸ Nitrate, nitrite, and ammonium analyses were obtained by ion chromatography. Analytical standard samples of munition chemicals have been described by Burrows.³

A reactor constant, i.e., a factor by which the detection limit exposure time (the time required to reduce munitions to their detection limits) for an 18 L sample should be multiplied to give the corresponding exposure time for a 10 gal (38 L) sample, was determined by comparing rates of photodegradation for 18 L and 36 L samples containing approximately 9 mg/L of TAX (Table A-1). From the detection limit exposure times, 7 and 9 minutes respectively,

it was determined that a factor of 1.32 should be employed to convert from 18 L to 38 L samples. This factor is used only in the economic analysis.

DISCUSSION

As demonstrated previously,⁴ ultraviolet photolysis of individual nitramines obeys mixed zero and first order kinetics, i.e.

$$a \frac{(C_0 - C)}{C_0} + b \ln \frac{C_0}{C} = kt$$

where $a + b = 1$ (Table 2*). A consequence of this behavior is that removal of nitramines, in terms of half-lives, becomes more efficient with diminishing concentrations, in contrast to a mass-driven process, such as carbon adsorption, which is more efficient at high concentrations. Thus, other things being equal, ultraviolet photolysis of wastewater is best effected just before its discharge.

In the case of the Holston AAP ILWTP, end-of-pipe treatment has the additional advantage that other organics, nitrates, and suspended solids have been reduced to very low levels (< 10 mg/L), thus greatly reducing the competitive absorption of ultraviolet radiation. In all cases studied, removal of nitramines from plant effluent to detection limits was achieved after less than 10 minutes exposure in the bench reactor.

However, since there was uncertainty concerning the nature and toxicity of photoproducts of the nitramines, it seemed advisable at the outset of this work to investigate treatment of wastewaters at the head of the plant as well, because the photoproducts would then be subjected to biochemical treatment before discharge. Three such wastewaters were studied: (1) the raw wastewater from the neutralization basin, which contains process waters from the post-digestion sludge thickener and suspended solids in the range of 20-40 mg/L; (2) the B-line effluent, which includes 85 percent of the flow and 100 percent of the nitramines, since the A-line includes wastes from acetic acid recovery only; and (3) anoxic filter effluent, which typically contains at least 30 mg/L of suspended solids.

When the plant is operating as designed, the B-line effluent is the cleanest wastestream in terms of suspended solids, although it has the highest nitramine content. The anoxic filter effluent has a lower nitramine content than the neutralization basin or the B-line effluents; it also contains a significant amount of suspended material, as does the neutralization basin. In practice, photolysis of the B-line nitramines to detection limits is no faster than for the neutralization basin, and the rate of nitramine removal from the anoxic filter effluent is nearly the same as for final plant effluent, in spite of the suspended material in the former (Tables A-2 through A-17). Observed removal time ranges are listed in Table 3.

* The equation, as stated in the earlier report, is in error. Table 2 includes corrected a, b, and k values for the original work.

TABLE 2. CORRECTED MIXED ZERO ORDER AND FIRST ORDER RATE ANALYSIS
FOR DESTRUCTION OF MUNITIONS^a

Munition	Init. Conc. (mg/L)	Conditions	Zero Order Fraction ^b	First Order Fraction ^b	k ^c min ⁻¹	Correlation (n)
TNT	18.23	UV/O ₃	0.80	0.20	0.0555	0.9978 (6)
TNT	22.41	UV/O ₃	0.90	0.10	0.0433	0.9998 (6)
RDX	12.61	UV/O ₃	0.15	0.85	0.374	0.9976 (6)
RDX	23.90	UV only	0.55	0.45	0.212	0.9998 (6)
RDX ^d	17.18	UV only	0.75	0.25	0.197	0.9991 (8)
HMX	2.67	UV/O ₃	1.0	0.0	0.363	0.9986 (3)
TAX	24.61	UV/O ₃	0.75	0.25	0.186	0.9997 (7)
TAX	22.94	UV only	0.65	0.35	0.191	0.9996 (7)
TAX ^d	28.47	UV only	0.70	0.30	0.134	0.9996 (9)
SEX	5.74	UV/O ₃	0.85	0.15	0.390	0.9979 (4)
SEX	4.95	UV only	0.25	0.75	0.669	1.0000 (4)
SEX ^d	11.85	UV only	0.73	0.27	0.283	0.9975 (7)

a. Data from Reference 4 except where noted.

b. Zero order and first order fractions which give best correlation.

c. By linear regression least squares.

d. This work.

TABLE 3. NITRAMINE REMOVAL TIMES BY ULTRAVIOLET RADIATION

Sample Point (No. of samples)	< 1 mg/L ^a min	< detection limits, ^b min
B-Line (3)	5 - 30	30 - > 30
Neutralization Basin (5)	7 - 15	15 - > 30
Anoxic Filter (2)	4 - 5	7 - 15
Plant Effluent (6)	2 - 7	7 - 10

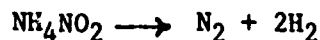
a. Sum of all nitramines.

b. Each individual nitramine.

PRODUCTS

Photolysis of RDX is considered to proceed through sequential loss of three equivalents of nitrous acid to s-triazine (Fig. 1). Glover and Hoffsommer have studied the ultraviolet photolysis of RDX under a variety of conditions.⁹ Besides nitrite ion, ammonia, formaldehyde, formamidine, and (tentatively) formic acid, they detected several nitrated acyclic materials believed to have arisen from hydrolysis of photointermediates.

As indicated earlier in this report, application of ultraviolet photolysis for destruction of nitramines in wastewater requires either that the products be relatively nontoxic or that they be destroyed in subsequent treatment. Therefore, in order to quantify the major products, pure samples of RDX (18 mg/L), TAX (28 mg/L), and SEX (12 mg/L) were photolyzed in deionized water (Tables A-18 - A-20). In each case studied, nitrite levels reached a maximum approximately 10 minutes after the corresponding nitramine had disappeared (Figs. 2 to 4). Nitrate was also a significant product, whether from air oxidation of nitrite or hydrolysis of an intermediate nitramine. Figure 5, an accounting of oxidized nitrogen with time, shows that loss of NO₂ from nitramines is at least 80 to 90 percent complete, assuming that all nitramine NO₂ is converted to nitrite and nitrate.* Furthermore, this is a minimum value, since it has been shown that ammonium nitrite decomposes under these conditions, and some product nitrite would not have been measured.¹⁰ Thus, nitrated materials of the



type identified by Glover and Hoffsommer are probably minor products when photolysis is taken to completion. Nitrite and ammonia are both known to exhibit significant toxicity to aquatic life. The US Environmental Protection

* The differences in shapes of the three curves is probably due more to concentration (TAX > RDX > SEX) than structure.

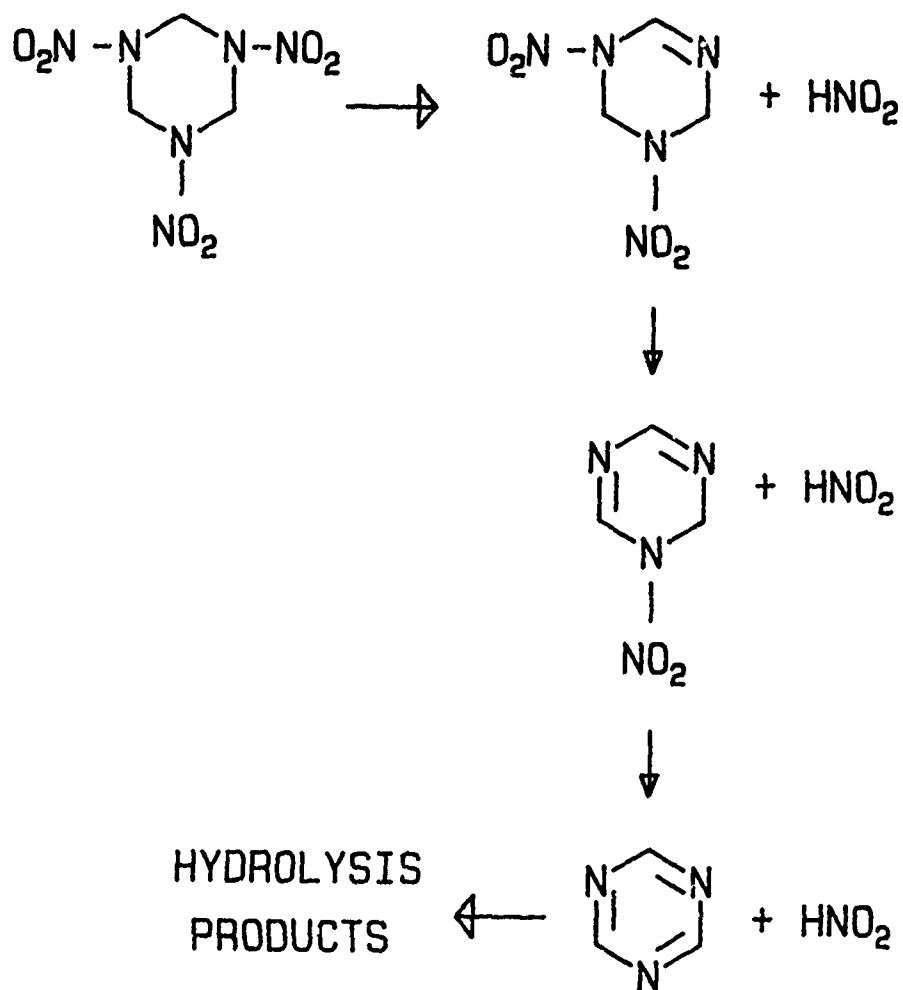


Figure 1. Products of RDX photolysis.

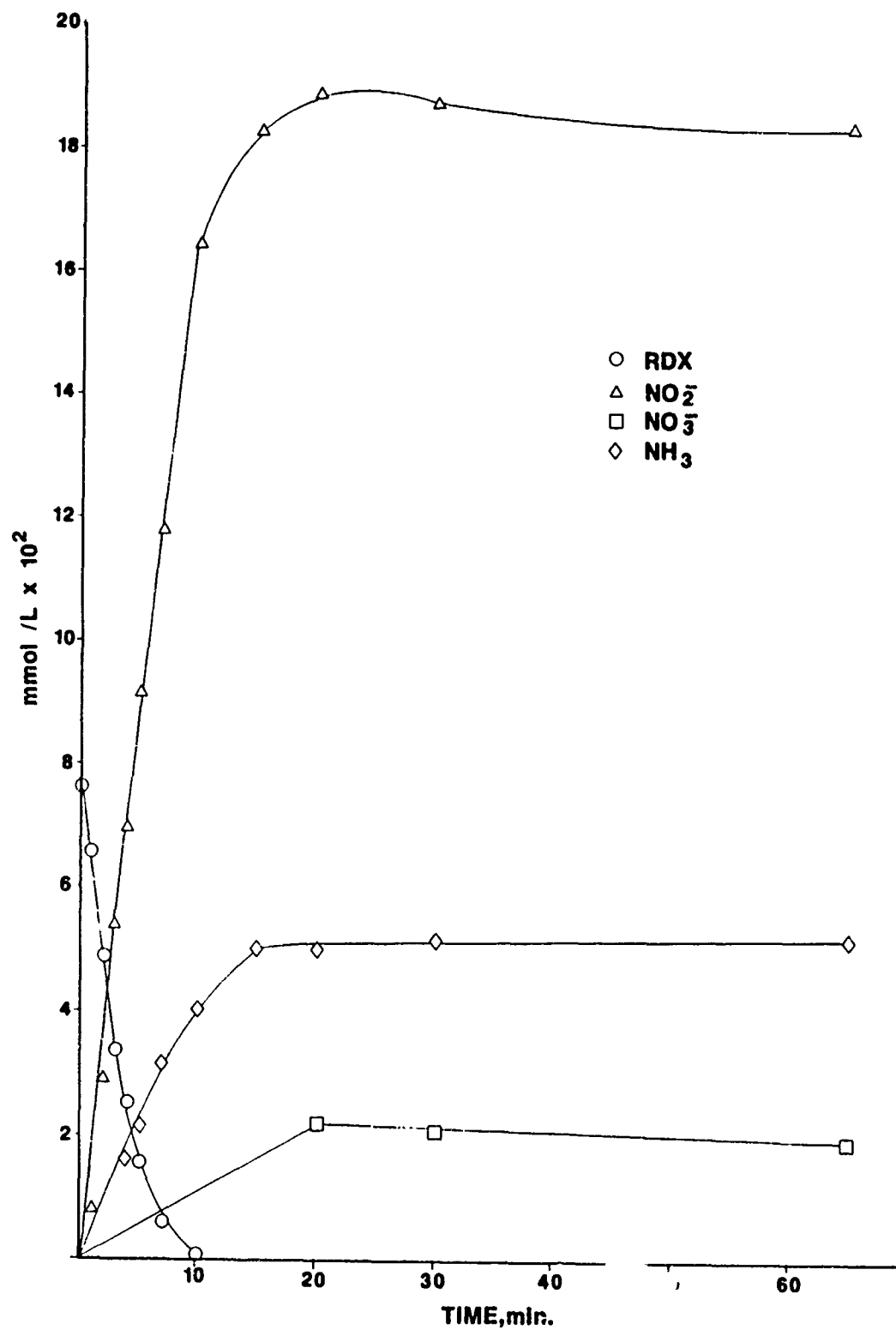


Figure 2. Photodegradation of RDX.

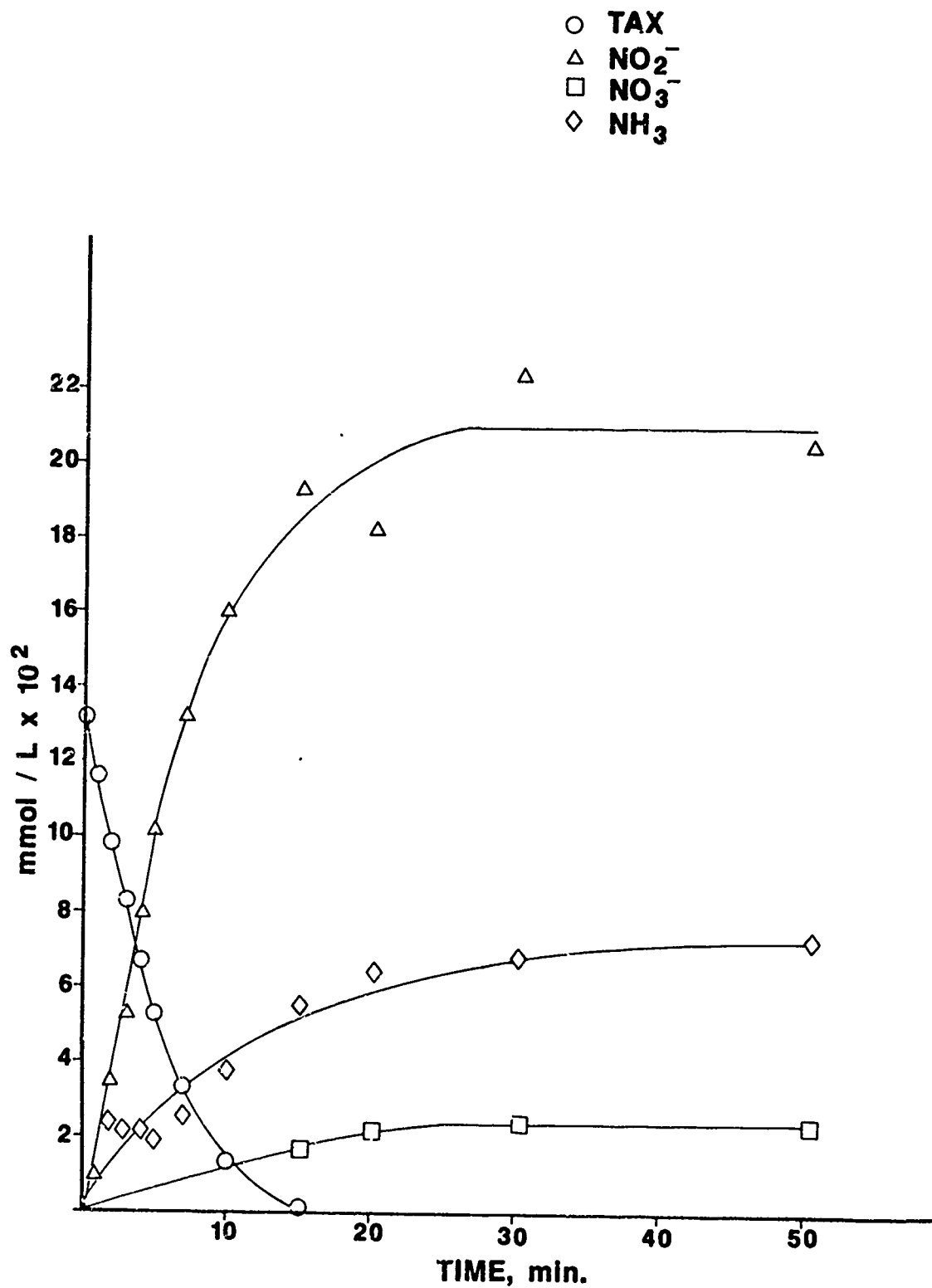


Figure 3. Photodegradation of TAX.

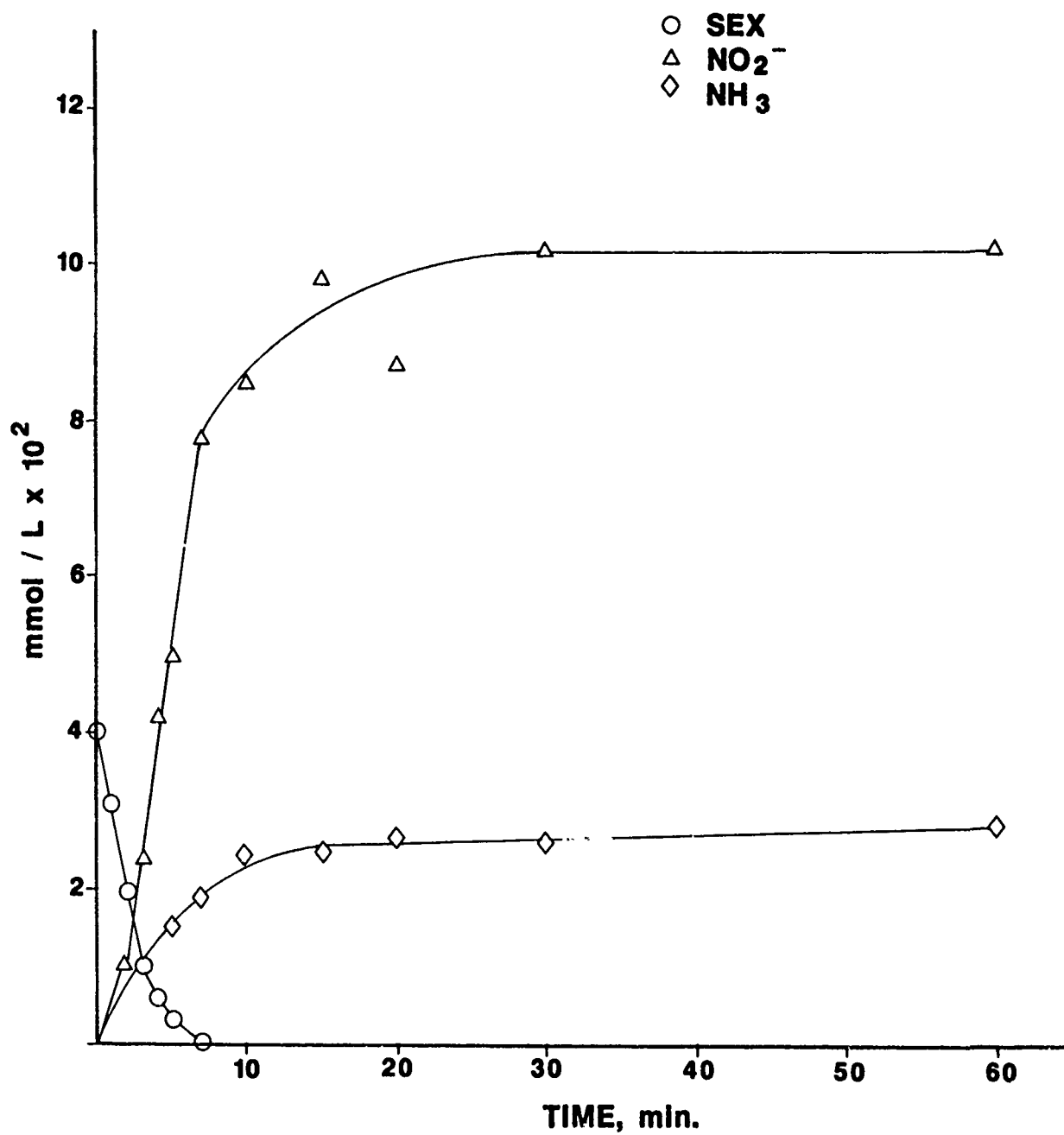


Figure 4. Photodegradation of SEX.

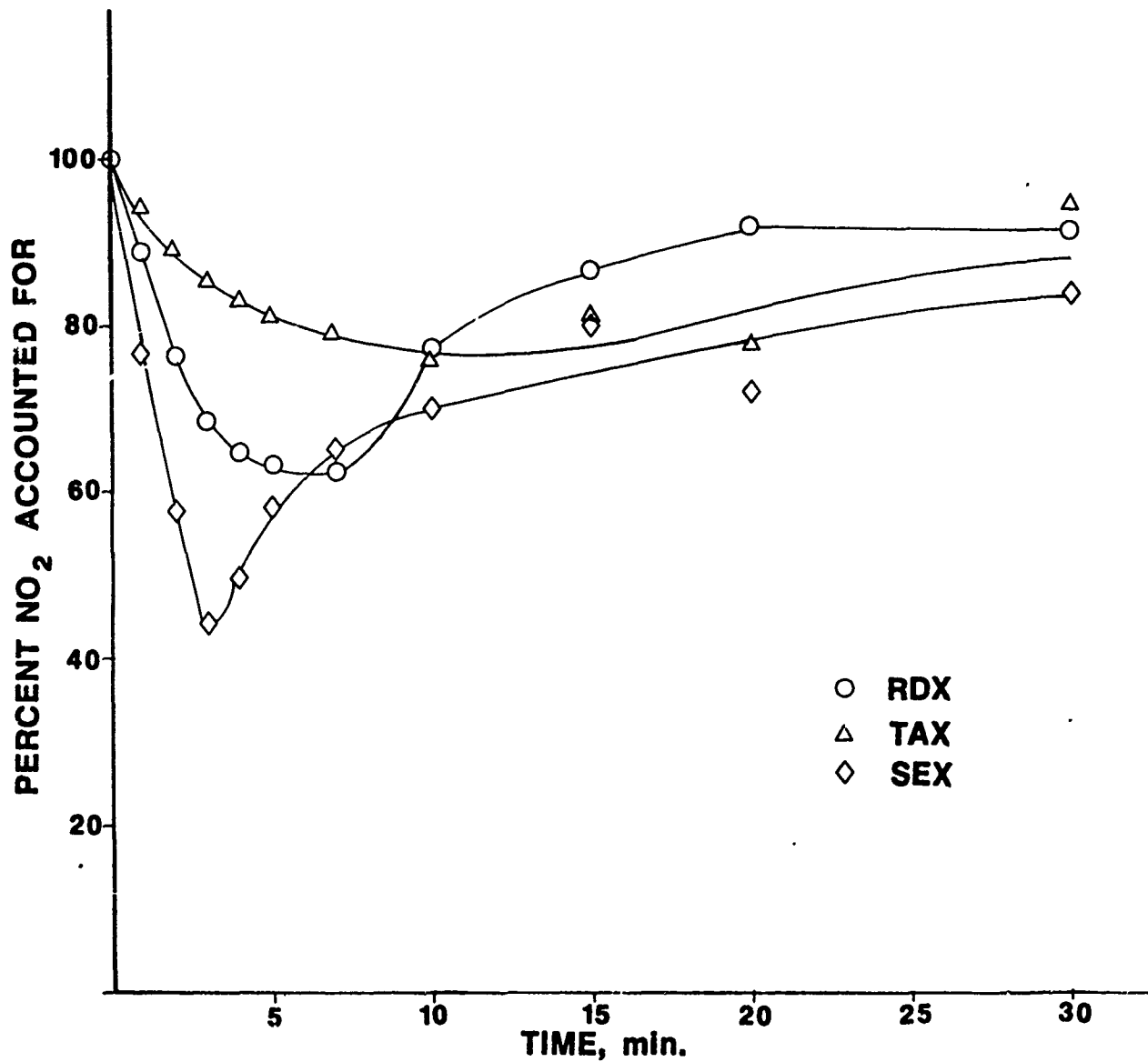


Figure 5. Nitramine photodegradation; oxidized nitrogen accounted for.

Agency (EPA) has published detailed pH-, temperature-, and species-dependent criteria for ammonia¹¹ and has suggested that limitation of levels of nitrite nitrogen to below 5 mg/L should be protective of most warm water fish.¹² EPA further states: "Recognizing that concentrations of nitrate or nitrite that would exhibit toxic effects on warm or cold water fish could rarely occur in nature, restrictive criteria are not recommended."

The Holston AAP NPDES permit sets a daily average effluent limit of 100 pounds of ammonia nitrogen for the summer months. This would correspond to 2 mg/L $\text{NH}_3\text{-N}$ at the present average discharge of about 6 mgd. Figures 2 to 4 show, quite consistently, 0.2 equivalents of ammonia present for each equivalent of nitramine photolyzed, which would correspond to 0.38 to 0.40 mg/L $\text{NH}_3\text{-N}$ for each 10 mg/L nitramine photolyzed. Since the 1985 Holston summer average $\text{NH}_3\text{-N}$ appears to fall well below 0.5 mg/L, it seems unlikely that additional ammonia generated by nitramine photolysis would create a wastewater discharge problem.

Glover and Hoffsommer measured 0.43 mol of formaldehyde for each mol of RDX destroyed, which would correspond to 0.58 mg/L for each 10 mg/L of RDX.⁹ Formaldehyde is not particularly toxic to fish at this level,¹³ though it is toxic to microorganisms.¹⁴ Ammonia, nitrite, and formaldehyde are all rapidly oxidized in the environment to relatively nontoxic materials, and it would appear safe and most efficacious to destroy nitramines by treatment of the final effluent, rather than an intermediate wastestream. Of course, if total nitrogen would otherwise exceed effluent limitations, it may be more efficacious to treat the wastestream for nitramine removal before it undergoes denitrification.

ECONOMIC ANALYSIS

The economic analysis for this system is based on a single favorable assumption: that the efficiency of any commercial reactor installed would be at least as high as provided by the bench unit used in these studies. Capital costs are based on low-maintenance packaged units featuring Teflon^R wastewater lines, slide-out lamp trays, and lamp failure indicators. These units, for which a price of \$5,000 per kw has been quoted,¹⁵ represent the most expensive option, but lower maintenance costs may offset the higher capital investment; also, a relatively low installation cost of 25 percent is estimated. No economies of scale are assumed. The final installation would consist of a preengineered building housing the required number of packaged units (occupying a total of approximately 25,000 ft³), plus on-line monitoring systems for nitramines and other parameters, as required. It would provide 1.76 watt-hr/gal average ultraviolet exposure for the plant effluent.

The principal operation and maintenance costs are power and ultraviolet lamp replacement. Lamps have an expected lifetime of one year. Other than lamp replacement (about eight per shift), labor requirements should be minimal. We have allotted one full-time equivalent to cover maintenance, monitoring, and reporting.

COST BASIS

Discharge at full mobilization:	12,600,000 gal	
Energy requirement:	80 watt/10 gal/10 min x 1.32*	
	= 1.76 watt-hr/gal	
	= 73.3 kw/mgd	
	= 924 kw for 12.6 mgd	
Reactor price:	924 kw x \$5,000/kw	= \$4,620,000
Installation:	0.25 x 4,620,000	= \$1,155,000
<u>Capital investment:</u>		= \$5,775,000
Ultraviolet lamps, 104 watt:	8885 x \$70	= \$622,000/yr
Power:	924 kw x 24 x 365	= 8,094,240 kw-hr/yr
	at \$0.03627/kw-hr ¹⁶	= \$293,580/yr
Labor:	2000 hr x \$20/hr	= \$40,000/yr
Unscheduled maintenance, etc:		= \$44,420/yr
<u>Estimated recurring annual costs:</u>		= \$1,000,000

*Reactor constant

The estimated uniform annual cost, based on a 12 year project, 1 year construction time, and no salvage value, is \$1,889,000, or \$0.41/1000 gal (Appendix B).¹⁷ This would be about 26 percent of the cost of Smith's most favorable carbon option.⁷ There are, of course, many uncertainties inherent in scaling up a 10 gal batch reactor to a 12,600,000 gal/day continuous reactor. Furthermore, the requirement that photolysis not only reduce nitramines to detection limits but destroys NO₂-containing photointermediates as well would double the exposure time needed as shown, e.g., in Figure 2. Finally, we have assumed (as has Smith⁷) that wastewater parameters will remain constant as full mobilization is attained, although it is more likely that contaminant levels will increase with increasing production. However, the results of this study suggest that pilot studies with a small commercial ultraviolet reactor should precede any decision to install tertiary treatment for removal of nitramines at Holston AAP or any future RDX facility.

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APPENDIX A

DATA FOR ULTRAVIOLET DEGRADATION OF NITRAMINES

TABLE A-1. COMPARISON OF
PHOTODEGRADATION RATES AS A
FUNCTION OF LIQUID DEPTH
IN REACTOR

Time, min	Tax, mg/L	
	18 L	36 L
0	8.783	9.047
1	6.130	7.083
2	3.272	4.383
3	1.530	2.887
4	0.735	1.887
5	0.299	1.066
6	0.094	0.412
7	<0.070	
9		<0.070

TABLE A-2. B-LINE EFFLUENT; COLLECTED 24 SEP 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	2.318	2.398	7.131	7.092
1	2.262	2.360	7.012	6.930
2	2.099	2.235	6.725	6.517
3	2.066	2.125	6.452	6.219
4	1.597	1.701	5.583	5.126
5	1.352	1.434	4.825	4.281
7	1.000	1.087	3.992	3.356
10	0.593	0.554	2.686	2.023
15	0.226	0.260	1.455	0.919
20	<0.070	0.085	0.646	0.335
30	<0.070	<0.070	0.107	<0.070

TABLE A-3. B-LINE EFFLUENT; COLLECTED 22 OCT 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.482	1.862	<0.070	6.811
1	0.352	1.833	<0.070	6.412
2	0.202	1.662	<0.070	5.566
3	0.104	1.511	<0.070	4.809
4	<0.070	1.215	<0.070	3.745
5	<0.070	1.080	<0.070	3.213
9	<0.070	0.684	<0.070	2.055
10	<0.070	0.390	<0.070	1.093
15	<0.070	0.143	<0.070	0.385
20	<0.070	<0.070	<0.070	0.127
30	<0.070	<0.070	<0.070	<0.070

TABLE A-4. B-LINE EFFLUENT; COLLECTED 27 OCT 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	2.014	1.970	4.567	5.029
1	1.957	2.004	4.612	5.025
2	1.638	1.682	4.007	4.244
3	1.559	1.525	3.795	3.916
4	1.239	1.114	3.100	3.062
5	1.058	0.836	2.598	2.444
7	0.563	0.538	1.634	1.480
10	0.323	0.283	1.094	0.856
15	0.116	0.098	0.420	0.266
20	<0.070	<0.070	0.135	0.077
30	<0.070	<0.070	<0.070	<0.070

TABLE A-5. NEUTRALIZATION BASIN WASTEWATER;
COLLECTED 21 SEP 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	2.649	1.409	1.829	4.222
1	2.650	1.629	1.802	4.150
2	2.480	1.549	1.621	3.643
3	2.129	1.469	1.434	3.119
4	1.635	1.125	1.072	2.117
5	1.413	1.029	0.917	1.719
7	0.878	0.575	0.550	0.920
10	0.386	0.395	0.230	0.308
15	<0.070	0.319	<0.070	<0.070
20	<0.070	0.278	<0.070	<0.070
30	<0.070	0.222	<0.070	<0.070

TABLE A-6. NEUTRALIZATION BASIN WASTEWATER;
COLLECTED 20 APR 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.107	1.245	2.390	2.545
1	1.021	1.100	2.155	2.215
2	0.854	0.865	1.725	1.648
3	0.696	0.658	1.331	1.162
4	0.498	0.455	0.910	0.733
5	0.357	0.321	0.619	0.463
7	0.216	0.188	0.311	0.197
10	<0.070	0.093	0.084	<0.050
15	<0.070	0.055	<0.070	<0.050
20	<0.070	0.053	<0.070	<0.050
30	<0.070	<0.050	<0.070	<0.050

TABLE A-7. NEUTRALIZATION BASIN WASTEWATER;
COLLECTED 25 JUN 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	2.539	1.519	3.247	4.121
1	2.526	1.492	3.221	4.012
2	2.313	1.310	2.832	3.410
3	1.914	1.084	2.326	2.658
4	1.606	0.850	1.919	2.056
5	1.198	0.672	1.583	1.612
7	0.828	0.394	0.961	0.835
10	0.421	0.198	0.498	0.352
15	0.077	<0.070	0.132	<0.070
20	<0.070	<0.070	<0.070	<0.070

TABLE A-8. NEUTRALIZATION BASIN WASTEWATER;
COLLECTED 27 JUN 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.043	2.800	3.168	3.416
1	0.702	2.487	2.879	3.086
2	0.660	2.335	2.695	2.848
3	0.487	1.824	2.087	2.085
4	0.325	1.534	1.719	1.553
5	0.227	1.198	1.344	1.104
7	0.150	0.803	0.872	0.599
10	0.126	0.466	0.422	0.186
15	<0.070	0.230	0.090	<0.070
20	<0.070	0.153	<0.070	<0.070

TABLE A-9. NEUTRALIZATION BASIN WASTEWATER;
COLLECTED 22 AUG 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.368	2.280	1.278	3.852
1	1.280	2.174	1.219	3.616
2	0.956	1.892	1.054	2.994
3	0.741	1.533	0.848	2.271
4	0.494	1.162	0.619	1.536
5	0.334	0.911	0.476	1.096
7	0.144	0.533	0.250	0.478
10	<0.070	0.078	0.087	0.128
15	<0.070	<0.070	<0.070	<0.070

TABLE A-10. ANOXIC FILTER EFFLUENT; COLLECTED 22 OCT 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.356	1.036	<0.070	1.043
1	0.294	0.909	<0.070	0.884
2	0.192	0.685	<0.070	0.810
3	0.176	0.410	<0.070	0.533
4	0.099	0.324	<0.070	0.388
5	0.093	0.096	<0.070	0.264
7	<0.070	<0.070	<0.070	0.105
10	<0.070	<0.070	<0.070	<0.070

TABLE A-11. ANOXIC FILTER EFFLUENT; COLLECTED 27 OCT 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.450	1.048	1.138	1.066
1	0.382	0.992	1.066	0.988
2	0.277	0.865	0.894	0.786
3	0.217	0.795	0.782	0.659
4	0.132	0.622	0.581	0.442
5	0.098	0.172	0.419	0.279
7	<0.070	<0.070	0.257	0.152
10	<0.070	<0.070	0.107	0.078
15	<0.070	<0.070	<0.070	<0.070

TABLE A-12. PLANT EFFLUENT; COLLECTED 21 FEB 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.966	1.201	0.162	2.504
1	1.427	0.793	0.108	1.488
2	1.071	0.567	0.078	0.985
3	0.773	0.435	0.073	0.908
4	0.695	0.326	<0.070	0.539
5	0.473	0.222	<0.070	0.277
7	0.194	0.084	<0.070	0.074
10	<0.070	<0.070	<0.070	<0.070

TABLE A-13. PLANT EFFLUENT; COLLECTED 20 APR 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.260	1.118	<0.070	2.129
1	1.177	1.006	<0.070	1.821
2	0.965	0.760	<0.070	1.308
3	0.690	0.485	<0.070	0.737
4	0.502	0.325	<0.070	0.418
5	0.362	0.220	<0.070	0.257
7	0.141	0.079	<0.070	0.059
10	<0.070	<0.050	<0.070	<0.050

TABLE A-14. PLANT EFFLUENT; COLLECTED 25 JUN 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	1.638	1.135	<0.070	2.443
1	1.489	1.000	<0.070	2.074
2	1.249	0.804	<0.070	1.579
3	0.894	0.539	<0.070	0.928
4	0.686	0.386	<0.070	0.591
5	0.342	0.270	<0.070	0.354
7	0.185	0.110	<0.070	0.120
10	<0.070	<0.070	<0.070	<0.070

TABLE A-15. PLANT EFFLUENT; COLLECTED 11 JUL 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.974	1.493	<0.070	3.590
1	0.630	1.312	<0.070	3.074
2	0.445	1.101	<0.070	2.448
3	0.352	0.749	<0.070	1.438
4	0.293	0.509	<0.070	0.868
5	0.207	0.366	<0.070	0.560
7	0.111	0.159	<0.070	0.171
10	<0.070	<0.070	<0.070	<0.070

TABLE A-16. PLANT EFFLUENT; COLLECTED 22 AUG 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.759	1.751	<0.070	2.271
1	0.490	1.211	<0.070	1.684
2	0.255	0.698	<0.070	0.920
3	0.133	0.394	<0.070	0.491
4	<0.070	0.195	<0.070	0.231
5	<0.070	0.106	<0.070	0.117
7	<0.070	<0.070	<0.070	<0.070

TABLE A-17. PLANT EFFLUENT; COLLECTED 24 SEP 85

Time, min	Nitramine, mg/L			
	SEX	HMX	TAX	RDX
0	0.479	1.696	<0.070	2.325
1	0.412	1.479	<0.070	1.968
2	0.253	1.102	<0.070	1.373
3	0.133	0.821	<0.070	0.967
4	<0.070	0.521	<0.070	0.545
5	<0.070	0.374	<0.070	0.368
7	<0.070	0.160	<0.070	0.116
10	<0.070	<0.070	<0.070	<0.070

TABLE A-18. PHOTODEGRADATION OF RDX

Time, min	RDX, mg/L	NO ₂ -N mg/L ^a	NO ₃ -N mg/L ^a	NH ₄ -N mg/L
0	17.180			<0.2
1	14.665	0.11		<0.2
2	10.842	0.41		<0.2
3	7.540	0.75		<0.2
4	5.528	0.98		0.23
5	3.607	1.28		0.30
7	1.306	1.65		0.44
10	0.122	2.31		0.56
15	<0.070	2.56		0.70
20		2.65	0.31	0.70
30		2.62	0.29	0.72
65		2.57	0.27	0.72

a. Unless otherwise indicated, below detection limits.

TABLE A-19. PHOTODEGRADATION OF TAX

Time, min	TAX, mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L
0	28.470	<0.1	<0.2	<0.2
1	25.528	0.15	<0.2	<0.2
2	21.315	0.49	<0.2	0.33
3	17.954	0.74	<0.2	0.30
4	14.498	1.10	<0.2	0.30
5	11.369	1.41	<0.2	0.27
7	7.248	1.83	<0.2	0.36
10	2.591	2.23	<0.2	0.53
15	0.344	2.69	0.24	0.75
20	<0.070	2.54	0.29	0.89
30		3.11	0.34	0.95
50		2.85	0.34	1.03

TABLE A-20. PHOTODEGRADATION OF SEX

Time, min	SEX, mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L
0	11.852	<0.1	<0.2	<0.2
1	9.128	<0.1	<0.2	<0.2
2	5.841	0.15	<0.2	<0.2
3	2.973	0.33	<0.2	<0.2
4	1.785	0.59	<0.2	<0.2
5	1.012	0.83	<0.2	0.21
7	0.107	1.09	<0.2	0.26
10	<0.070	1.20	<0.2	0.34
15		1.38	<0.2	0.35
20		1.22	<0.2	0.37
30		1.42	<0.2	0.36
60		1.43	<0.2	0.39

APPENDIX B

ECONOMIC ANALYSIS¹⁷

ULTRAVIOLET SYSTEM

Project Costs, \$1,000,000

Project Year	Investment	Recurring Cost	Discount Factor	Discounted Annual Cost
1	5.775		0.954	5.509
2		1.000	.867	.867
3		1.000	.788	.788
4		1.000	.717	.717
5		1.000	.652	.652
6		1.000	.592	.592
7		1.000	.538	.538
8		1.000	.489	.489
9		1.000	.445	.445
10		1.000	.405	.405
11		1.000	.368	.368
12		1.000	.334	.334

Total Discounted Project Cost: 11.704

Uniform Annual Cost: $11.704 / (7.149 - 0.954) = 1.889$

Cost/1,000 gal: \$0.41

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